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Proposal for a Search for Highly Ionizing Particles for the DO Area at Fermilab

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Summary

We propose to use thin arrays of plastic track detectors, covering a large solid angle, to search for new particles created in the DO area with ionization rate greater than that of a minimum ionizing particle with charge 20e. The large center-of-mass energy available for particle production and the special features of plastic track detectors will permit a search for particles with masses much greater than can be produced at other accelerators. The arrays will contain two types of detectors--CR-39 and Lexan--which have been calibrated with heavy ion beams. We have shown that CR-39 has a higher charge resolution than that of any other detector of comparable thickness and a sensitivity adequate to detect magnetic monopoles with β as low as $\sim 10^{-2}$ and charged particles with Z/β as low as ~10. The background of spallation recoil tracks produced by interactions of stray hadrons in the plastics is $<10^{-2}$ as great in Lexan as in CR-39. Thus, although it is sensitive only to particles with $Z/\beta \gtrsim 60$, Lexan serves as a useful complement to CR-39 if the stray hadron background is high. The array of thin plastic stacks can be configured in a variety of ways so as to coexist with other proposed detectors. Two obvious modes of operation are: (1) to intercept all solid angles not used by a coexisting detector; (2) to use thin (~0.3 g/cm^2) plastic arrays of large solid angle inside a coexisting detector. To achieve maximum integrated luminosity it may be necessary to construct a remotely controllable retractor that removes the plastic arrays used in the first mode when the ratio of background flux to luminosity is high.

Introduction

High-resolution track-recording plastics[1] provide a very powerful way to search for new particles with very high ionization rate such as quark-nucleus complexes[2] and magnetic monopoles, with minimal interfering background from synchrotron radiation, stray hadrons and other lightly ionizing radiation. With an automated retractor that removed their plastic detectors to a shielded area during injection, Kinoshita et al.[3] were able to expose their detectors to an integrated luminosity of 8×10^{36} cm^{-2} at an average distance of only ~7 cm from an unshielded interaction region at PEP. They have recently reported results of the first year of a two-year search at PEP for electrically and magnetically charged particles with ionization rate greater than that corresponding to $Z/\beta \sim 20$. The 95% confidence-level upper limit on the cross section for producing such particles was reported by them[3] to be 0.9×10^{-36} cm^2. Although they expect to reduce this limit by at least an order of magnitude in the next year, the center-of-mass energy available for particle production at PEP is limited to ~29 GeV. By exploiting the much higher energies available at proton-antiproton colliders, the authors of the present proposal hope to discover new particles or to extend the current mass limits. We have completed extensive studies of the backgrounds existing in the interaction regions at PEP and believe that our CR-39 plastic track detectors can successfully function in the radiation background which will exist in the DO area.

Description of the Proposed Detector

Figure 1 shows the two configurations that we successfully used with D. Fryberger in the PEP experiment.[3] In the unshielded IR-10 we used a motor-driven wheel to transport a claw-shaped array between its normal position next to the IR and its shielded position near the floor ~6 ft below the IR. In IR-6, which contained well-designed masks in the beam pipe at either end of the IR, we were able to leave detectors in place during injection with no significant background. At IR-6 we shared the solid angle with a quark-search experiment, as shown in Fig. 1. In the early stages of our experiment we used small pieces of CR-39 and Lexan plastic at various locations to map out the background and arrive at an optimum configuration of thin-walled beam pipe, detector position, retractor wheel and shielded area.

At the DO area we propose to use stacks of CR-39 and Lexan of thickness and size optimized to obtain the maximum integrated luminosity compatible with coexisting experiments. Of the experiments suggested in the Fermilab Report of June, 1981, those presented by B. Pope, M. Marx et al., and A. Erwin et al. appear to have an open configuration such that it should be possible to place transportable CR-39 and Lexan detectors in the unused portions of solid angle. In the early stages of the experiment we envisage leaving 1 cm-thick arrays in position throughout a complete running period and placing small, individual pieces of CR-39 and Lexan at various positions to establish the background radiation pattern. As the luminosity improves, we may find it necessary to provide a remotely controllable retractor to move the detectors in and out of the interaction region so that the accumulated background is kept as low as possible.

We have had an opportunity to expose a small stack, three sheets thick, of CR-39 plastic, to an integrated luminosity of 10^{30} cm^{-2} at the CERN-SPS collider, at a radial distance 29 cm from the center line and 356 cm from the intersection region. The background was tolerable. We know nothing about the proton and antiproton currents. Presumably the ratio of luminosity to current will eventually greatly increase, so this test should be regarded as very encouraging.

We propose to test a second configuration which, once high luminosity and stable performance of the collider are attained, will give us a very large solid angle and have almost no adverse effect on coexisting experiments. This configuration is a thin jacket of CR-39 and Lexan of maximum thickness ~0.3 g/cm^2, between the beam pipe and the innermost portion of a coexisting detector. Other experiments being proposed will study lightly ionizing, highly penetrating particles which will suffer almost no change of energy in passing through 0.3 g/cm^2 of plastic. This thickness corresponds to only ~500 μm of additional thickness of a steel beam pipe.

We will optimize the thickness of CR-39 and Lexan sheets so as to minimize the background of etched-through spallation-recoil tracks without undue sacrifice of our detector sensitivity to new particles. Exposure times will be governed by the rate of background accumulation due to passage of stray hadrons through the plastic sheets.

Detector Capability

CR-39, whose remarkable track-recording properties were discovered in our laboratory,[4] has a much higher sensitivity and resolution[1,5] than any other plastic track detector. Figures 2 and 3 show the response of CR-39 to nuclear fragments with $\beta = 0.94$ produced in the fragmentation of high-energy Ar and Fe at the LBL Bevalac. Figure 4 shows the response as a function of Z/β for three different processing conditions. Figure 5 shows the velocity dependence of the ionization rate of a monopole with $g = 137e$ as calculated by Ullman[6] and Ahlen[7]. Using an ammonia rapid-scanning technique, we will be able to detect $Z/\beta \gtrsim 20$.

By a proper choice of detector sheet thickness and processing conditions we will be able to identify monopoles with magnetic charge as low as the Dirac charge, $g_D = 137e/2$, having velocities as low as 0.02c. If monopoles with large mass and low velocity are created, their ionization rate will be too low to detect with plastic detectors less sensitive than CR-39. Using CR-39 detectors it will also be possible to detect hypothetical electrically charged particles such as quark-nucleus complexes,[7] which might exceed the threshold of $Z/\beta \gtrsim 20$.

Lexan, with a minimum detectable Z/β of ~60, is much less sensitive than CR-39. We will use it to extend our search to much greater integrated luminosities than may be possible with CR-39. It could provide more stringent limits on the cross sections for producing new particles with $Z/\beta \gtrsim 60$. Our accelerator calibrations showed that the track accumulation rate in a background of hadrons is $<10^{-2}$ as large in Lexan as in CR-39.

Beam Time Requirements

As soon as there is a successful colliding beam we would like to conduct preliminary tests on our detectors, possibly in the BO area, which should not result in any inconvenience or loss of time to existing detectors. Our tests would consist of placing small (~several cm^2) pieces of CR-39 in various locations to map out and assess the backgrounds in order to determine the optimum detector configuration. As the time scale for construction of our detectors is relatively short, we expect to be prepared for running before the DO area first establishes colliding beams, now estimated to be sometime in 1983.

Requests of the Fermi National Laboratory

We propose to cover the expenses of preparing the detectors, traveling

References

1. S.P. Ahlen, P.B. Price and G. Tarlé, Physics Today 34, 32 (1981).
2. A. de Rujula, R.C. Giles and R.L. Jaffe, Phys. Rev. D 17, 285 (1978).
3. K. Kinoshita, P.B. Price and D. Fryberger, Phys. Rev. Lett. 48, 77 (1982).
4. B.G. Cartwright, E.K. Shirk and P.B. Price, Nucl. Instr. and Meth. 153 457 (1978).
5. G. Tarlé, S.P. Ahlen and P.B. Price, Nature 293, 556 (1981).
6. J.D. Ullman, Phys. Rev. Lett. 47, 289 (1981).
7. S.P. Ahlen, Rev. Mod. Phys. 52, 121 (1980).

to and from Fermilab, processing detectors and analyzing the data, assuming our present NSF grant for our PEP experiment continues.

We need to enlist the cooperation of groups designing detectors with which ours might coexist, so that our detectors can be accommodated from the beginning.

We request that Fermilab provide the resources for installing our detectors or for an automated retractor if such a scheme is found to permit a large improvement in integrated luminosity.

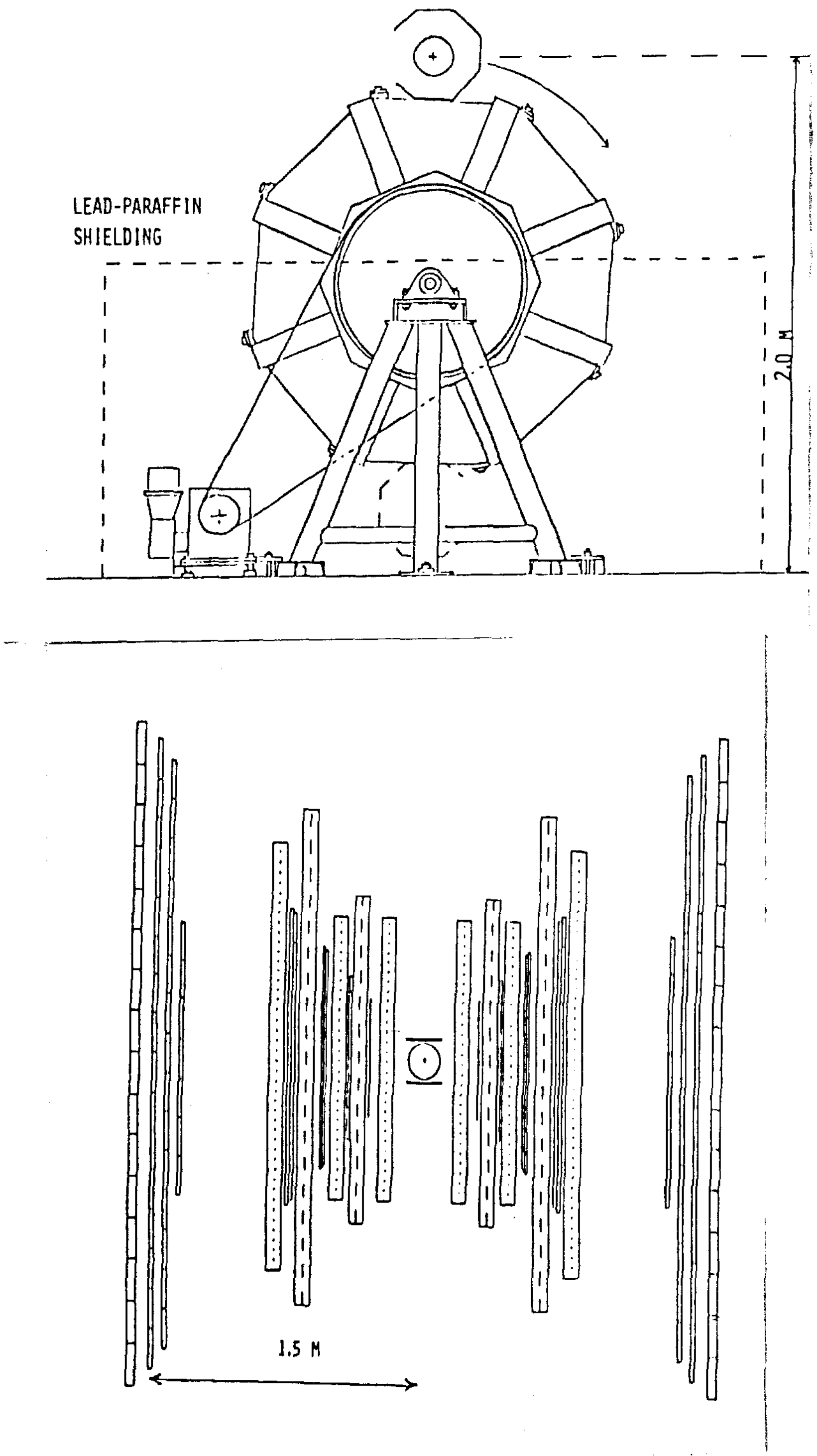

Figure 1. Detectors used at the SLAC-PEP e^+e^- collider:
top: at IR-10, detector stacks arranged in "C" shape, rotate into shielded area during beam injection
bottom: at IR-6, plastic detectors are above and below the pipe and detectors for the Free Quark search are on the sides.

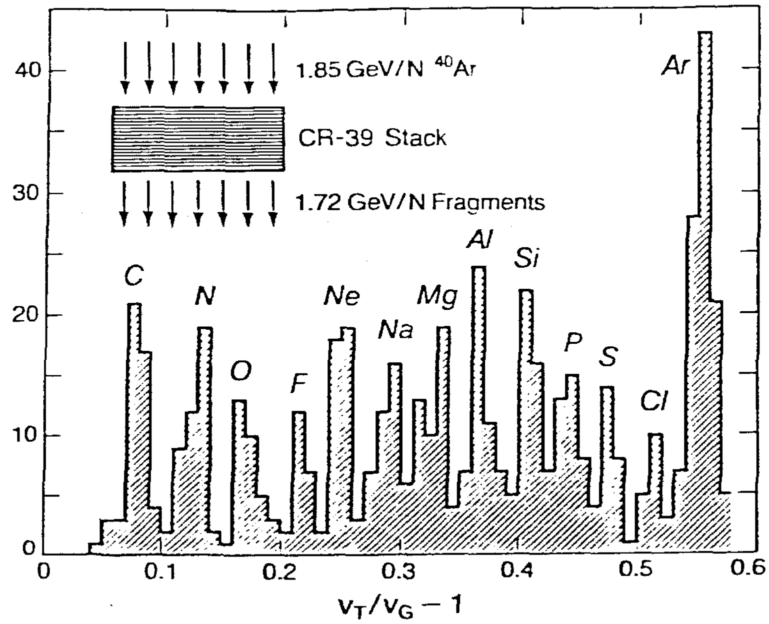

Figure 2. Reduced etch rates for fragments of 1.8 GeV/amu Ar interactions, determined from single etch pit diameters in CR-39 etched at 70° C.

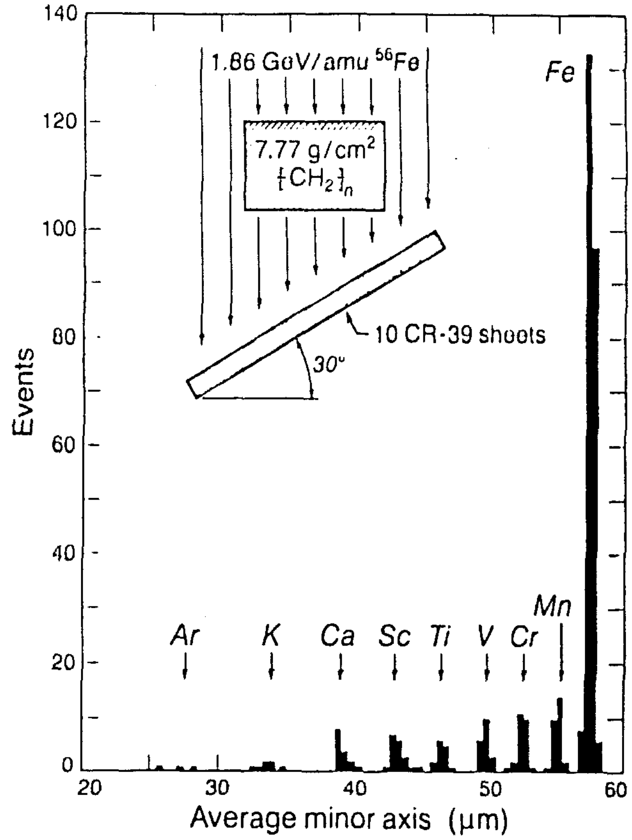

Figure 3. Averages of four successive etch pit minor axes for fragments of 1.86 GeV/amu Fe interactions in CR-39 (doped with DOP) etched at 40° C.

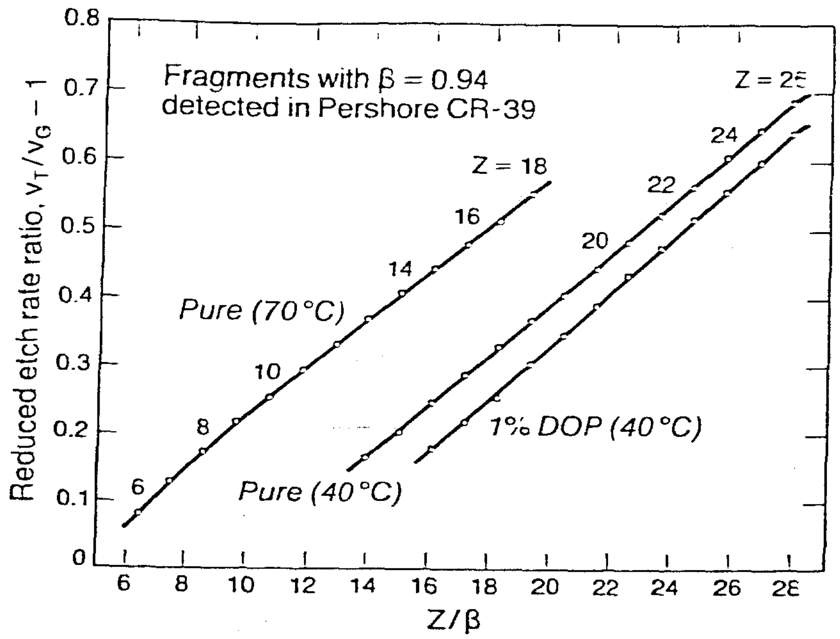

Figure 4. Dependence of reduced etch rate on Z/β in several experiments.

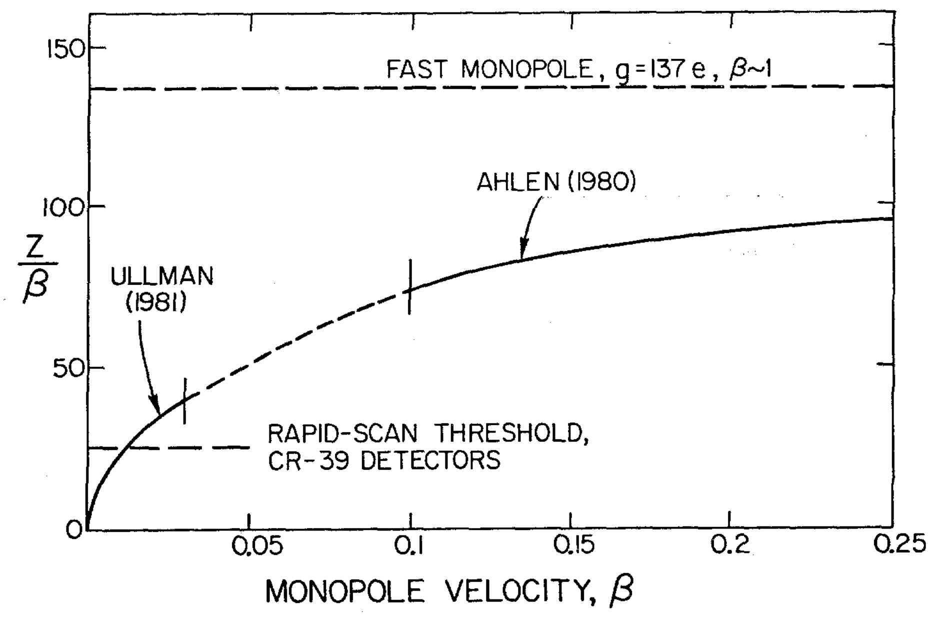

Figure 5. Ionization rate (in units of equivalent Z/β) of a monopole of strength g = 137e and velocity βc.